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Accelerating Energy Efficiency Improvements in Room Air Conditioners in India: Potential, Costs-Benefits, and Policies

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Disclaimer

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Executive Summary

Rising incomes, increasing urbanization, and large cooling demand prompted by India's hot, humid climate are driving increasing uptake of room air conditioners (ACs). Air conditioning already accounts for 40-60% of summer peak load in large Indian cities such as Delhi and is on track to contribute 140 gigawatts (GW) (~30%) to peak demand in 2030. India's standards and labeling policies improved the market average efficiency of room ACs by about 35% between 2006 and 2016 (3% per year) even as inflation-adjusted room AC prices continued to decline. In this report, we assess the technical feasibility and costs and benefits of accelerating the efficiency improvement in room ACs in India and discuss policy enhancements needed to achieve this goal.

We also describe examples of rapid AC efficiency improvement from Japan and Korea. Driven by appropriate policies and programs, AC efficiency in these countries improved by more than 8% per year, resulting in near-doubling of energy efficiency over seven to ten years while inflation-adjusted AC prices declined. We also find that the most efficient room AC sold on the Indian market is almost twice as efficient as the average AC sold on the market in 2015-16. As a result, we conclude that the technology needed to accelerate room AC efficiency in India is available.

If, starting in 2018, the market average room AC efficiency improves by 6% per year instead of the current 3% per year, about 39 GW of peak load (equivalent to about 80 power plants of 500 MW each), and more than 64 TWh per year of energy (equivalent to the current electricity consumption of the entire state of Gujarat) could be saved by 2030. The net present value (NPV) of the consumer benefit between 2018 and 2030 would range from rupees (Rs) 4,000 crore or US$600 million (if room AC prices increase as expected based on estimates of current cost of efficiency improvement) to Rs 173,000 crore or US$25 billion (if room AC prices do not increase with efficiency improvement, as has been the case historically). Although the rebound effect could reduce the financial benefit of efficiency improvements, it would not affect the overall consumer welfare benefit.

This benefit is achievable by ratcheting up India's one-star efficiency level (the de-facto minimum energy performance standard) for room ACs to the level of the current (2016) five-star rating by 2022 and to the level of current best available technology on the market by 2026. Bulk procurement, similar to that used in UJALA LED Program, and incentive programs would be crucial for accelerating the market transformation, especially pulling up the top of the market. Similar programs could be implemented for other types of ACs.

Accelerating Energy-Efficiency Improvements in Room Air Conditioners in India: Potential, Costs-Benefits, and Policies

Nikit Abhyankar, Nihar Shah, Won Young Park, Amol Phadke

1 What is at Stake: The Need to Meet Space Cooling Demand Sustainably

India's hot, humid climate prompts substantial demand for space cooling, and air conditioner (AC) use is increasing rapidly with the country's rising incomes and increasing urbanization (Phadke, Abhyankar, & Shah, 2013). Room ACs account for 99% of all ACs purchased, and their sales have grown at a compounded annual growth rate (CAGR) of 12.5% per year between 2005 (1.3 million) and 2014 (3.7 million) (Phadke et al., 2013; PWC, 2015; Shah, Waide, & Phadke, 2013). An AC is highly electricity intensive; at full load, a typical room AC consumes about 150 times the power of a light-emitting diode (LED) bulb or 20 times the power of a regular ceiling fan.[1] Because many parts of India routinely experience extremely hot temperatures, increasing the availability and affordability of space-cooling technologies including fans and ACs is (along with improving building design to ensure thermal comfort) an important opportunity to improve health and economic well-being. A recent study by Davis and Gertler (2015) shows that India has largest AC market growth potential in the world because of the country's large population and large number of cooling degree days[2] (Figure 1), low but increasing incomes, and extreme temperatures that are rising due to climate change. India's Bureau of Energy Efficiency (BEE) has highlighted the nation's concern about the already large electricity demand from ACs, which BEE estimated at 60-80 terawatt hours (TWh) in 2014 (Diddi, 2014). In addition, where AC penetration is significant, it has a large peak load impact. For example, in New Delhi, cooling accounts for 40-60% of the summer peak load. In parts of the world that have even higher AC penetration (as a percentage of population), such as Australia, the peak load can triple on hot days (Figure 2).

[1] ACs in India commonly have a cooling capacity of 1.5 tons, i.e. roughly 5.25 kilowatts (kW) of cooling. At an Indian seasonal energy-efficiency ratio (ISEER) of 3.5, this equals roughly 1.5 kW of power consumption, which is roughly 150 times the power consumption of a 10-watt (W) LED bulb or 20 times that of a regular ceiling fan consuming about 75W.

[2] Cooling Degree Days: A cooling degree day is a unit used to estimate the need for space cooling based on the daily temperature. Annual cooling degree days are calculated by subtracting 65 from a day's average temperature in Fahrenheit and adding the results over a year.

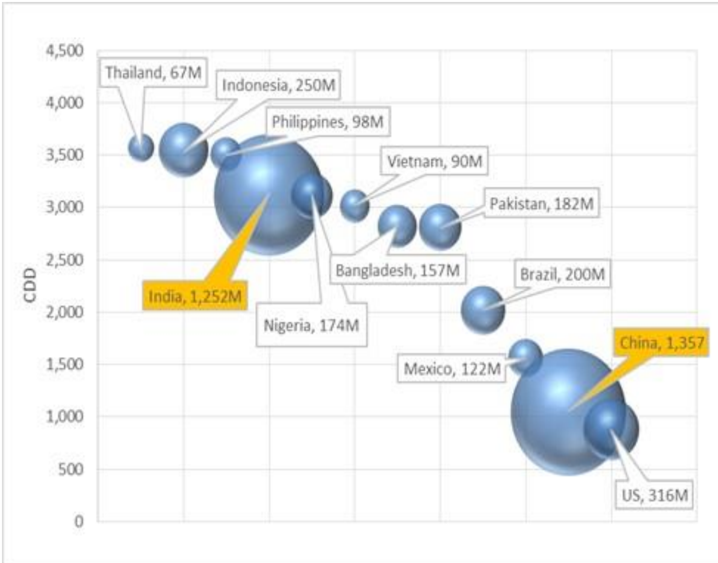


Figure 1: Top 12 countries by air-conditioning potential measured in cooling degree days (CDD); the size of the bubble indicates the relative population size (Source: Davis and Gertler, 2015)

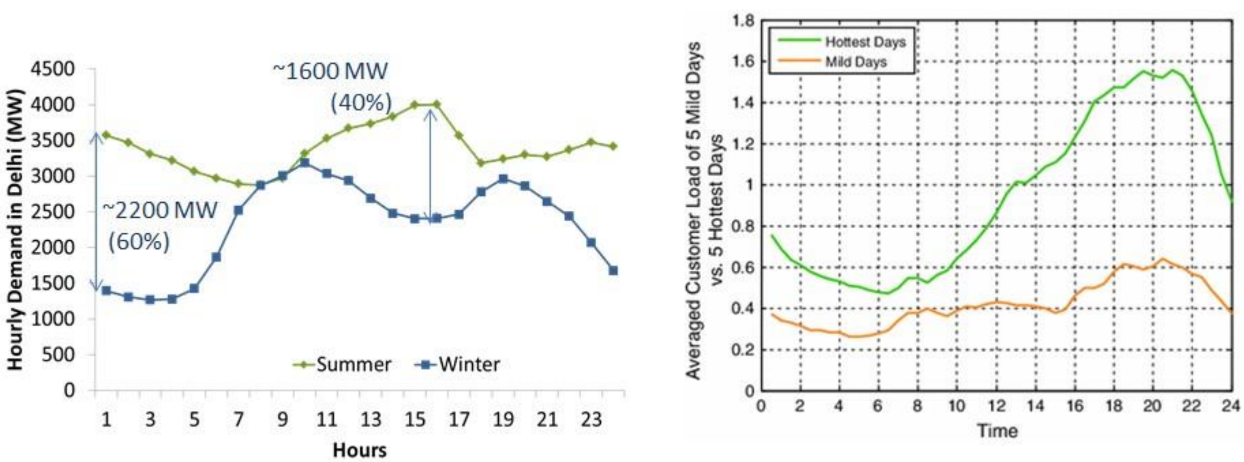


Figure 2: Space-cooling load in New Delhi is 40-60% of summer peak load (left); AC can triple load in the hottest areas of the world, e.g., New South Wales, Australia (right)

Data sources: (DSLDC, 2012; Smith, Meng, Dong, & Simpson, 2013)

Room AC penetration was a little more than 5% in urban India in 2011 (NSSO, 2012; Shah et al., 2013). For comparison, room AC penetration in urban China grew from about 5% in 1995 to more than 130% in 2012 (IBISWorld, 2013; Zhou et al., 2012). In the absence of additional policy interventions, i.e., under a business-as-usual (BAU) scenario, room AC penetration is expected to rapidly increase in India and could add about 140 GW to the peak demand (equivalent to about 300 power plant units of 500 MW each) by 2030 and between 300-500 GW by 2050 (Phadke et al., 2013; Shah, Wei, Letschert, & Phadke, 2015a); these values are equivalent to about 30% of the projected peak loads in 2030 and 2050 (Abhyankar et al., 2013; NITI Aayog, 2015).

A holistic strategy is needed to sustainably meet the challenge of growing electricity demand from room ACs. This document presents a vision for efficient air-conditioning equipment in India, focused mainly on mini-split room ACs. We draw on Indian and international experience with policies that can drive rapid adoption of efficient air-conditioning equipment. We underscore that, although our focus is on increasing the AC efficiency, it is only one strategy for meeting cooling demand sustainably. Improving efficiency needs to be complemented by other strategies that reduce cooling demand (e.g., employing cool roofs, efficient building design, and energy management systems) and that deliver cooling efficiently at minimal cost (e.g., using efficient ceiling fans).

The remainder of the report is organized as follows. In Section 2, we review the current status and trends related to room AC efficiency in India and summarize the policies that India has used to drive room AC efficiency. In Section 3, we summarize similar experience in Japan and Korea where room AC efficiency has almost doubled over approximately 10 years and draw insights relevant to future policies to accelerate room AC efficiency improvement in India. In Section 4, we assess the technical feasibility and costs-benefits of scenarios for rapidly improving AC efficiency in India and discuss policies that can be used to achieve this goal. In Section 5, we discuss the key policy and program options in India for accelerating the room AC efficiency improvement.

2 Room Air-conditioner Efficiency and Policies in India

India's Energy Conservation Act of 2001 provides the legal and institutional framework for the Government of India to promote energy efficiency across all sectors of the economy. BEE was created under the Ministry of Power to implement the Energy Conservation Act.[3] BEE launched a voluntary standards and labeling (S&L) program in May 2006 with an overarching agenda to reduce the energy intensity of electrical appliances. The labels use a comparative five-star rating system based on annual or daily energy consumption. The labeling scheme combines the comparative star labels with minimum energy performance standards (MEPS); products that meet the relevant MEPS are awarded one star. Products awarded the five-star level are the most efficient on the market, meeting the most stringent consumption requirements in the program. In 2012, mandatory labeling was introduced for split and window fixed speed room ACs (BEE, 2012).

[3] The Energy Conservation Act was amended in 2010 to empower BEE to accredit energy auditors and to hire its own staff, and the Central Government to issue energy savings certificates.

Historically, BEE has revised its efficiency performance criteria and the energy-efficiency ratio (EER) of the star levels every two years (see Table 1), giving approximately two years advance notice of implementation of new performance levels so that the AC industry has time to adjust its supply.

Table 1: BEE star rating levels for split ACs effective January 2012 through December 2015

	Star Levels for Split ACs (1 Jan 2012 - 31 Dec 2013)	
	Minimum EER (W/W)	Maximum EER (W/W)
1-Star	2.50	2.69
2-Star	2.70	2.89
3-Star	2.90	3.09
4-Star	3.10	3.29
5-Star	3.30	

	Star Levels for Split ACs (1 Jan 2014 - 31 Dec 2015)	
	Minimum EER (W/W)	Maximum EER (W/W)
1-Star	2.70	2.89
2-Star	2.90	3.09
3-Star	3.10	3.29
4-Star	3.30	3.49
5-Star	3.50	

Source: BEE (2012, 2014)

In June 2015, BEE adopted a voluntary label for split inverter ACs with a one-star level of 3.1 and a five-star level of 4.5, using the newly adopted Indian seasonal energy-efficiency ratio (ISEER) metric, which is based on International Standards Organization (ISO) standard 16358 but uses an India-specific temperature distribution.[4] Table 2 shows the minimum and maximum ISEER levels for inverter AC labels.

Table 2: BEE star rating levels for inverter ACs effective June 2015 through December 2019

	Star Levels for Inverter ACs (29 June 2015 - 31 Dec 2019)	
	Minimum ISEER (Wh/Wh)*	Maximum ISEER (Wh/Wh)
1-Star	3.1	3.29

[4] ISO adopted 16358 in 2013 to provide an international standard for rating fixed-speed and inverter (or variable -speed) ACs under the same metric. This metric (cooling season performance factor [CSPF]/heating season performance factor [HSPF] or annual performance factor [APF]) allows a weighted average to be calculated based on a country- or region-specific temperature bin. This framework has the advantage of using the same test points as the ISO 5151 rating standard for ACs, making for a smoother transition to rating of inverter and fixed-speed ACs under the same metric while also capturing the benefits of the part-load savings available under a seasonal metric. For cooling-only operation, this metric is known as CSPF. In 2015, BEE has adopted ISO 16358 but modified the temperature-bin distribution to account for the hotter weather in India and to calculate the ISEER metric for fixed-speed and inverter ACs. BEE has adopted the ISEER metric to measure room AC performance in India in the future (Shah et al., 2016).

2-Star	3.3	3.49
3-Star	3.5	3.99
4-Star	4.0	4.49
5-Star	4.5	

*Wh – Watt-hours

Source: (BEE, 2015)

The ISEER metric captures the efficiency benefits of part-load operation of room ACs. Inverter ACs that employ variable-speed drives, can operate at part-load while fixed speed ACs can operate only at full load. The ISEER metric and the star labels shown in Table 2 are due to become mandatory for all ACs (fixed-speed and inverter ACs) in 2018.

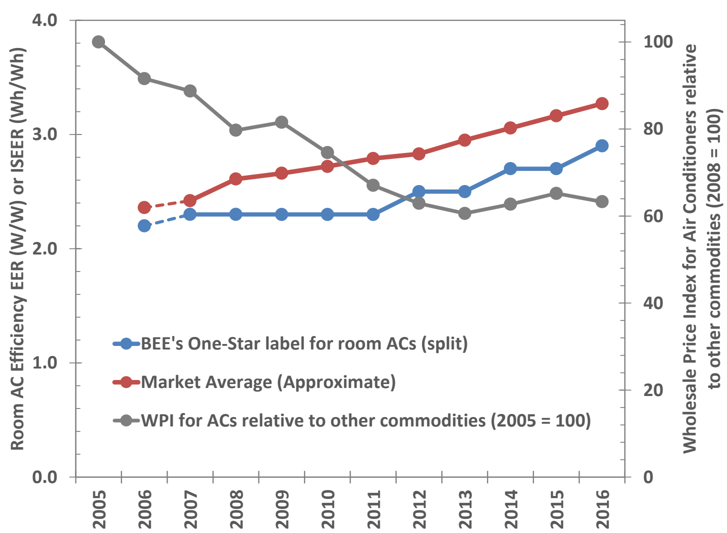


Figure 3: Trends in room AC efficiency improvement and decline in AC prices in India (2005-2016)

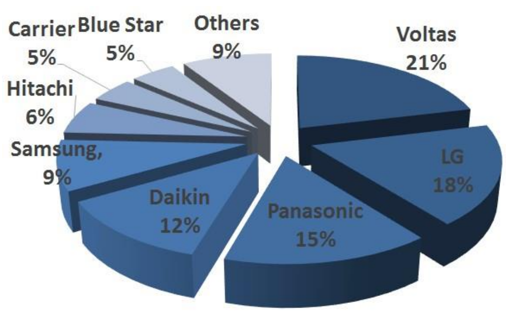
Note: The one-star or MEPS value for 2007 was proposed and was not mandatory. The 2006 value is taken as a notional minimum value, which was used by BEE to estimate the benefits of the labeling program (BEE, 2008). Similarly, the market average for 2006 has been taken as the baseline value used by (McNeil & Iyer, 2008).
Data sources: (BEE, 2008, 2009, 2010, 2012, 2014; McNeil & Iyer, 2008; OEA, 2015, 2016, PWC, 2012, 2015)

The MEPS (one-star label) for room ACs increased by about 35% from 2006 to 2016, i.e., at about 3% per year (Figure 3). Market-average room AC efficiency has typically been slightly higher than the one-star level and has improved similarly. Even with these efficiency improvements, inflation-adjusted room AC prices, measured by the wholesale price index (WPI) relative to the basket of all commodities, fell by nearly 35% during the same time period. Although the MEPS and the five-star level for inverter ACs will be ISEER 3.1 and ISEER 4.5, respectively, until 2019, the most efficient room AC already commercially available in India has an efficiency of ISEER 5.8 (with cooling capacity of 1 ton); moreover, several brands have models with efficiency between ISEER

4.5 and 5 (see Figure 8). Going forward, if the historical trend of approximately 3% efficiency improvement each year continues, the market average efficiency of ACs in 2026 will be ISEER 4.3, well below the efficiency of the most efficient room AC sold in India in 2016. However, if India takes an accelerated efficiency-improvement pathway in which today's most efficient technology becomes the market average in 10 years, efficiency would improve by nearly 100% by 2026. In the next section, we describe how such accelerated improvements in room AC efficiency have been achieved in Japan and Korea.

3 Air-Conditioner Efficiency in Japan and Korea: Examples of Accelerated Efficiency Improvement Driven by Policy

Japan and Korea have seen rapid improvements in room AC efficiency. We summarize below the policies aimed at increasing room AC efficiency in those countries and their impact on efficiency and prices. From this summary, we draw insights about strategies to increase the rate of improvement in room AC efficiency in India. Japanese and Korean brands have more than 60% of the market share in the Indian room AC market (see Figure 4), so the experience with AC improvement in these countries is particularly relevant for India.



Total room AC sales (2014) = 3.7 million units
Data source: PWC (2015)

Figure 4: Room AC market shares in India in 2014

3.1 Japan

Figure 5 shows trends in room AC efficiency in Japan, reported as coefficient of performance (COP) and annual performance factor (APF), as well as room AC prices represented by inflation-adjusted consumer price index (CPI) for room ACs. The figure also shows relevant details of the timing and targets of efficiency policies.

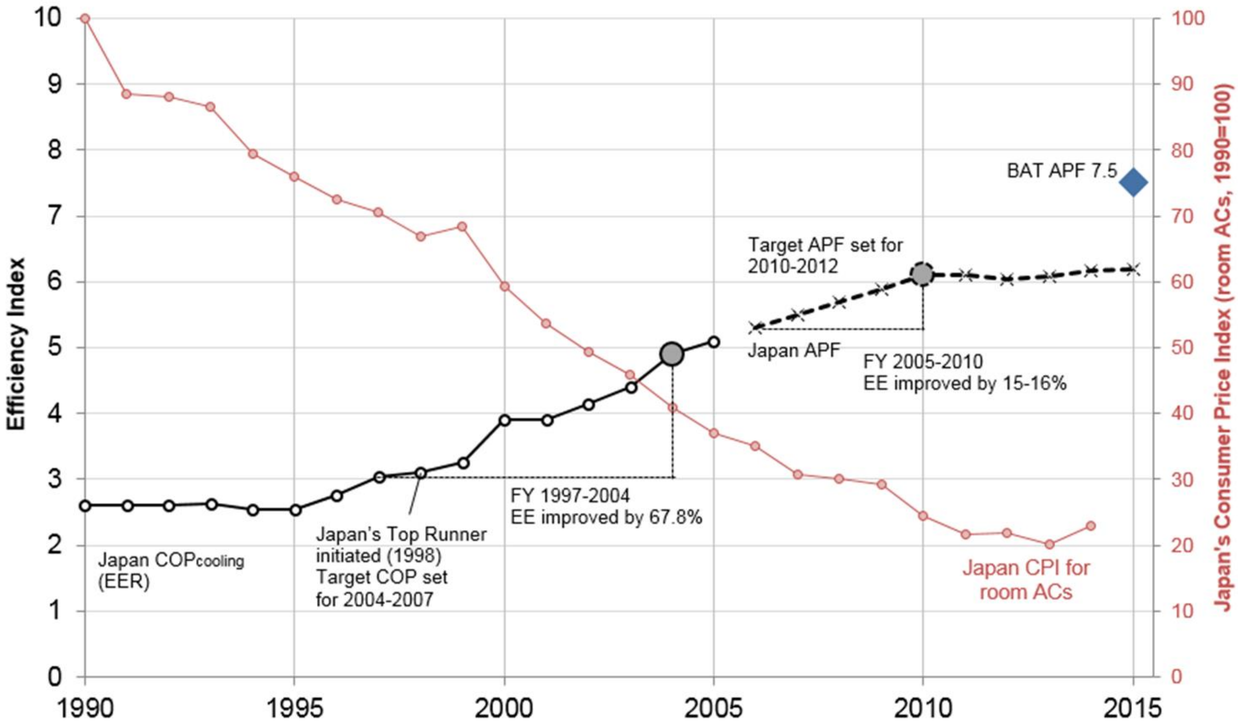


Figure 5: Room AC efficiency trends and price indices in Japan

Sources: (Kimura, 2010) for COPs (EERs) for 1970-2005. Japan's APF for 2006-2015 is a product- weighted average estimated based on (ECCJ, 2015) . CPI is taken from (SBJ, 2014). Dotted lines are authors' estimates.

One of the main policies to promote room AC energy efficiency in Japan is the Top Runner program launched in 1997. The program mandated that, by 2004, all AC manufacturers had to have a sales-weighted, fleet-average COP of 5.3 (W/W) for small ACs and 4.9 (W/W) for larger ACs, which was ~60% more efficient than the market average efficiency in 1997 (representing an improvement of more than 7.5%/year). This target COP was determined by the COP of the most efficient AC model available on the market at the time. Industry met this target by producing more efficient ACs and discontinuing the sale of inefficient ACs. Manufacturers used several technical measures to improve efficiency, including incorporating variable-speed compressors, micro-channel heat exchangers, and electronic expansion valves. Significant efficiency improvements were also achieved by increasing the size of heat exchangers and increasing refrigerant flow. Between 1995 and 2005, room AC efficiency in Japan improved by nearly 100% (from a COP of 2.55 to 5.10, a rate of 7.2% per year). Prior to the Top Runner program, room AC efficiency had not improved substantially over time in Japan.

In 2006, a new target was established for 2010, which required a further improvement of about 20%. The efficiency metric was changed to APF to enable accurate crediting of the savings achieved by variable-speed/inverter ACs and their performance in both cooling and heating mode. Industry also met the 2010 target.

After 2009, AC efficiency improvement in Japan was partially aided by financial incentives related to the Japanese government's Eco-Point System. That system awarded "eco-points" for the purchase of consumer products that rated four or more stars in the national system of energy-efficiency standards. Starting in 2011, only five-star appliances were eligible for eco-points. Consumers earned eco-points by buying four kinds of government-designated high-efficiency products: ACs, refrigerators, televisions, and LEDs. The points, worth ¥1 each, could be exchanged for three types of goods: coupons and prepaid cards, high-efficiency products, or products that promoted regional economies. Overall, the program was successful; the share of four- and five-star products increased from 20% to 96% for ACs, from 30% to 98% for refrigerators, and from about 84% to 99% for televisions. The total budget amounted to US$8.7 billion (de la Rue du Can et al., Leventis, Phadke, & Gopal, 2014).

Figure 5 also shows the inflation-adjusted CPI for room ACs in Japan. The inflation-adjusted CPI can be used as a proxy for room AC prices. It appears that the rate of reduction in prices did not change significantly even as efficiency improved substantially. Since 1996, efficiency has improved by more than 90%, and inflation-adjusted prices declined by more than 80%. There was no clear trend of increasing electricity prices while efficiency was improving, so it is not likely that changes in electricity prices were a driver for accelerating efficiency improvement.

3.2 South Korea

In 1992, the Korean government implemented the Energy-Efficiency Label and Standard Program to improve the energy efficiency of key products, including appliances and vehicles, that account for a majority of the country's energy consumption (Lee, 2010). Mandatory MEPS were published in 2002 and took effect in 2004 for window and split AC units up to 23-kW cooling capacity. In September 2011, the government launched the Energy Frontier Program, which sets energy-efficiency criteria for key appliances at 30-50% more efficient than grade 1 (which was the most efficient criterion in 2011). The first phase of the program included four major appliances: TVs, refrigerators, ACs, and clothes washers (Lee, 2010).

Box 1: Comparing ISEER and Other Efficiency Metrics

The ISEER metric may not be directly comparable to the Japanese APF or Korean SEER levels presented in this report, primarily because of the differences in AC efficiency test points used in each country. For example, the ISEER calculation requires testing only at full-load and half-load operation at 35°C and at 29°C (measured capacity and power input at full- and half-load operation at 35°C and ISO 16358-determined default coefficients for capacity and power input at full- and half- load operation at 29°C). Korea's and Japan's CSPF calculations accept test points at full-, half-, and minimum-load operations at 35°C and at 29°C (Phadke et al., 2016). The Korean and Japanese metrics might be able to capture the savings from variable-speed drives when a unit operates at less than half load whereas ISEER could not capture these savings. However, given climate conditions and usage patterns in India, ACs are unlikely to operate below half load there for significant amounts of time, so such savings might not be significant in the Indian context. In general, the efficiency of an AC unit measured using ISEER would be lower than that measured using the Korean CSPF or Japanese APF. In addition, the Japanese APF considers efficiency performance in heating mode. Phadke et al. (2016) find that if the Japanese and Korean ACs were tested under ISEER test conditions, their Japanese APF and Korean CSPF values would lower by 10% and 13% on average, respectively, when converted to ISEER. For some of the most efficient models, ISEER values would be as much as 20% lower than the Japanese APF and Korean CSPF values.

Samsung and LG together make up more than 80% of the Korean AC market. Industry experts indicate that both brands want most of their models to qualify under the Grade 1 or the Frontier criteria to be competitive in the market. Therefore, these efficiency requirements, despite being voluntary, have likely driven overall efficiency improvement in ACs on the Korean market.

Figure 6 shows that the Grade-1 efficiency criterion has increased efficiency requirements by more than 100% since 2008, and most new models by LG and Samsung meet either the Grade 1 or the Frontier criteria, resulting in significant improvement in average AC efficiency compared to 2008 levels. The share of inverter/variable-speed ACs increased from less than 10% to more than 90% within a span of eight years, and efficiency improved by more than 100% (~12% per year). During this period, inflation-adjusted room AC prices (CPI) continued to decline.

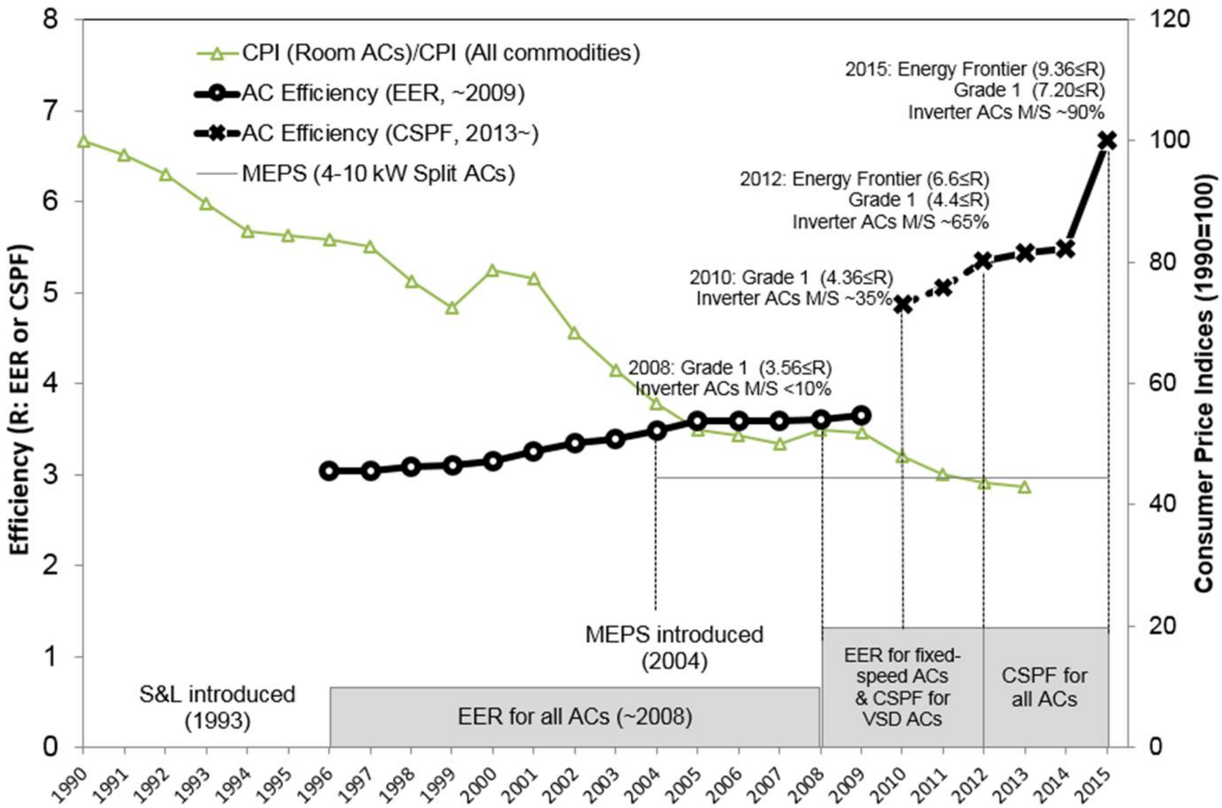


Figure 6: Trends in room AC efficiency and price indices in Korea

Sources: EERs for 1996-2008 are product-weighted averages (IEA, 2010). Mixed efficiencies with EER and CSPF for 2009-2010 and CSPF for 2013-2015 are product-weighted averages estimated using Korean Energy Agency's (KEA's) database (KEA, 2015). CPIs are from (KOSIS, 2014). Variable speed drive (inverter) ACs are estimated to account for more than 85% of the AC sales in the market in 2013 and more than 90% of AC sales in 2015 (KEA, 2015). The dotted lines are authors' estimates.

As in Japan, the accelerated improvement in AC efficiency in South Korea was aided by a downstream financial incentive program. This program, called "Carbon Cashbag," was launched in October 2008 and operated by the Ministry of Knowledge Economy and Korean Energy Management Corporation.[5] Consumers who purchase low-carbon products get carbon credits from manufacturers, retailers, or banks that participate in the Carbon Cashbag program. Points are then stored on a Carbon Cashbag card and can be used for discounts on public transportation, basic utilities charges, purchases of other efficient appliances, or tickets to cultural events. Carbon Cashbag is a voluntary program. Companies (mostly appliance manufacturers) that register in the program benefit from reductions in advertising fees and other public incentives (de la Rue du Can et al., 2014). Another type of financial incentive

[5] The Ministry of Knowledge Economy and the Korea Energy Management Corporation have now been renamed as the Ministry of Trade, Industry and Energy, and the Korea Energy Agency, respectively.

program in South Korea was “feebate,”[6] in which revenues from a 5- to 6.5% tax on energy-consuming home appliances subsidized low-income households’ purchases of highly efficient products (de la Rue du Can et al., 2014).

The key insights from experiences in Japan and Korea are that aggressive MEPS revisions have played a critical role in accelerating room-AC efficiency improvement, and innovative incentive programs played an important but complementary role in the overall market transformation. In the next section, we assess the technical feasibility, impact, and costs and benefits of accelerated AC efficiency improvement in India.

4 Technical Feasibility, Impact, and Costs-Benefits of Accelerated Air-Conditioner Efficiency Improvement in India

We assess the technical feasibility, peak demand, and electricity consumption impacts as well as the costs and benefits of accelerated room-AC efficiency improvement in India compared to a BAU scenario. In the BAU scenario, we take the BEE star levels up to 2019 and assume that the one-star level is ratcheted up at the historical rate of 3% per annum, reaching an ISEER of 4.2 by 2030. In the accelerated efficiency-improvement scenario, we assume that the room AC MEPS is revised to ISEER 3.5 in 2018 (compared to 3.1 specified by BEE) and is ratcheted up thereafter at 6% per annum, which is double the historical rate. Over the next six years, the five-star AC efficiency level in 2016 (ISEER 4.5) becomes the MEPS (one-star level) by 2022. Over the next 10 years, i.e., by 2026, the room AC MEPS would nearly double the current level (from ISEER 2.9 to 5.7); by 2030 the room AC MEPS would reach an ISEER of 7.1, an improvement in the MEPS of about 140% in 15 years. Figure 7 shows the room AC MEPS (one-star levels) up to 2030 for the two scenarios, BAU and accelerated efficiency improvement.

[6] A feebate is a tax or “fee” on less-efficient equipment that is used to fund a rebate on more efficient equipment. If designed and monitored carefully, this financing mechanism can be a revenue-neutral policy and can be independent of government general budgets. However, careful, continuous monitoring is required to make sure the balance is maintained (de la Rue du Can et al., 2014).

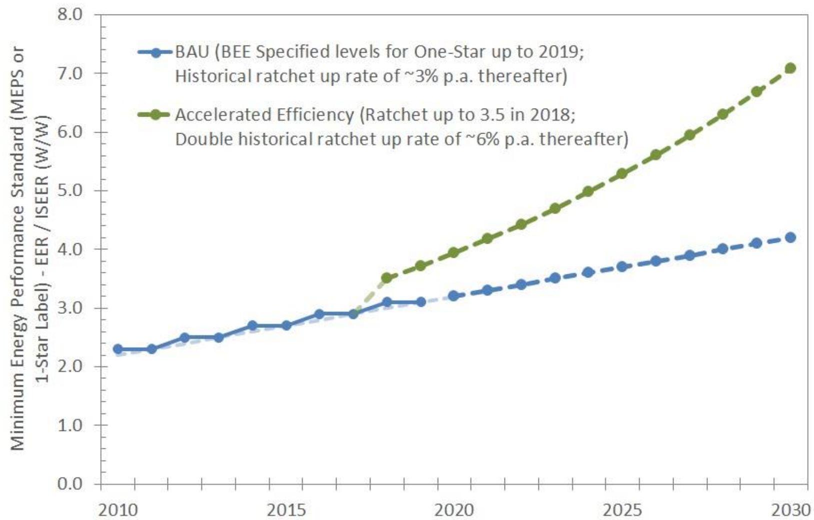


Figure 7: Alternative trajectories for room AC minimum standard (one-star level) improvement

As discussed in the previous section, Japan and Korea have achieved similarly aggressive efficiency improvements. In Japan, during a 10-year period between 1995 and 2005, room AC efficiency improved by nearly 100%. In Korea, between 2007 and 2015, room AC efficiency improved by more than 80%.

4.1 Technical Feasibility of the Accelerated Efficiency-Improvement Scenario

The accelerated efficiency-improvement scenario implies that the most efficient room AC sold currently on the Indian market (ISEER of 5.8)[7] will become the market average efficiency level in 2024 whereas one of the most efficient room ACs on the global market today (Korean cooling-season performance factor [CSPF] of 9.4, which is about 15-20% lower when converted to ISEER)[8] will be the market average efficiency in 2030. Figure 8 shows ISEER levels of most inverter AC models registered with BEE as of April 2017, arranged by cooling capacity. The figure also shows the BEE-specified one-star and five-star levels for inverter ACs up to 2019.

[7] Model # Daikin JTKM35SRV16 with cooling capacity of 1 ton
[8] Model # Samsung AF18J9975WWK with 2-ton cooling capacity

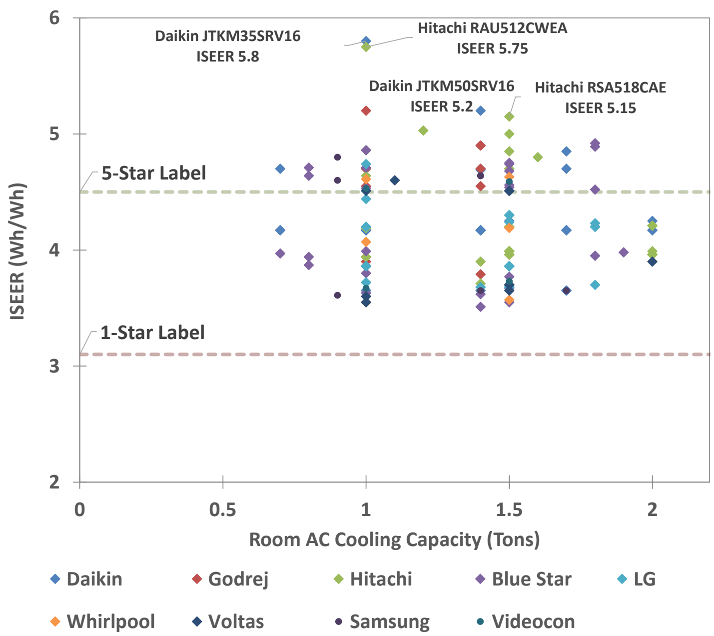


Figure 8: Spread of inverter room- AC products offered by manufacturers, by cooling capacity (as of April 2017)

Note: Each point refers to a room AC model on the market. The most efficient model, offered by Daikin (model #JTKM35SRV16), has an ISEER of 5.8 for a cooling capacity of 1 ton. The most efficient ~1.5-ton-capacity model is Daikin JTKM50SRV16 with ISEER of 5.2.
Data source: (BEE, 2017)

As shown in Figure 8, most brands in India already have room AC models with ISEER >4.5, which is the one-star level suggested by 2022 in the accelerated efficiency-improvement scenario. That is, manufacturers appear to already have the technology to meet the mandatory one-star requirement in the accelerated efficiency-improvement scenario. Note that the ISEER of 5.8 (as well as Korean CSPF of 9.49) has been achieved for capacities smaller than 1.5 tons, which is the most commonly used room AC size in India. Anecdotal interviews with industry experts indicate that there should not be any technical constraints in achieving similar ISEER in 1.5-ton models as well. Improving efficiency beyond the Korean CSPF of 9.4 for 1.5-ton models will require additional research and development. Some future directions to improve efficiency include employing separate sensible and latent cooling (dehumidification); evaporative pre-cooling; desiccant-based dehumidification; M-cycle-based evaporative cooling; absorption and adsorption cooling; solar cooling; and thermoelectric, magnetocaloric, and elastocaloric cooling. Also, the Kigali Amendment adopted in October 2016 regarding the phasedown of the

[9] The Korean CSPF of 9.4 is equivalent to approximately ISEER 7.9 based on the differences in test conditions in the two countries (Phadke et al, 2016). If the Japanese and Korean ACs were tested under ISEER test conditions, their Japanese APF and Korean CSPF values would decrease by 10% and 13% on average, respectively, when converted to ISEER; for some of the most efficient models, ISEER values would be as much as 20% lower than Japanese APF and Korean CSPF values.

hydrofluorocarbons (synthetic gases used as refrigerants in room ACs) will affect AC efficiency. Our previous reports have shown the efficiency benefits of switching to alternative refrigerants (Shah, Wei, Letschert, & Phadke, 2015b).

4.2 Impact of Accelerated improvement in Air-Conditioner Efficiency

In this section, we show the impacts of accelerated AC efficiency improvement on total energy consumption and national peak load. We also show the net consumer benefit of this efficiency improvement trajectory.[10]

4.2.1 Reduction in Electricity Consumption and Peak Load

Figure 9 shows the total energy consumption attributable to room ACs at bus-bar[11] for both scenarios. By 2030, under the accelerated efficiency- improvement scenario, room AC consumption could be reduced by nearly 64 TWh/yr at bus-bar without compromising any cooling service provided by room ACs. This is equivalent to the total energy generation from nearly 40 GW of solar photovoltaic (PV) capacity and is in line with BEE's estimates (Diddi, 2014).

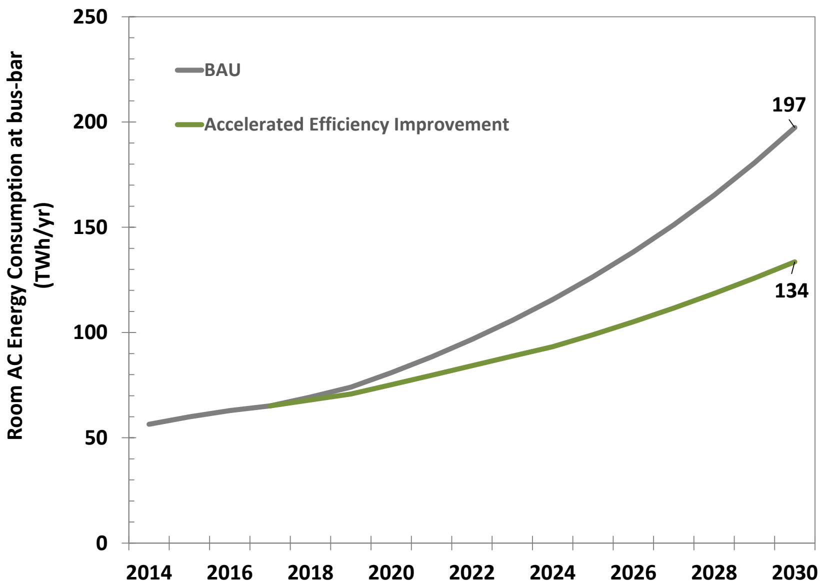


Figure 9: Energy consumption for alternative trajectories for room AC efficiency improvement

Note: These energy consumption projections are preliminary estimates that we believe are conservative.

As mentioned previously, room ACs are already a major contributor to peak load in major

[10] Assuming transmission and distribution loss of 15%. See Appendix for additional details on data, methodology, and assumptions used to estimate the impact of the accelerated efficiency improvement scenario.

[11] Consumption at bus-bar implies consumption at the high-voltage transmission substation level. This includes the (technical) transmission and distribution losses of the grid and is directly comparable to electricity generation capacity. See Appendix for more details.

urban areas. In the BAU trajectory, we project that, by 2030, the peak load from room ACs would be about 134 GW at bus-bar, which is equivalent to nearly 30% of the projected total peak load in 2030. Peak load is estimated using a peak coincidence factor of 0.7; i.e., at most, about 70% of the room AC stock operates coincident with each other. Please refer to the Appendix for more details on this projection. Room AC efficiency improvement would result in significant peak-load savings, as shown in Figure 10.

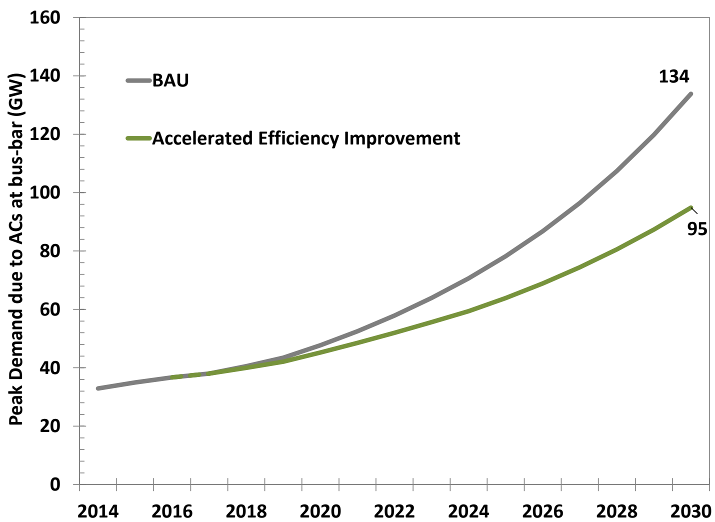


Figure 10: Peak load for alternative trajectories for room AC efficiency improvement

By 2030, under the accelerated efficiency-improvement scenario, peak demand could be reduced by nearly 40 GW. This is equivalent to avoiding the construction of 80 large coal-fired power plants of 500 MW each.

4.2.2 Net Consumer Benefit

We estimate the net consumer benefit for a given level of cooling service is the net present value (NPV) of the electricity bill savings from increased efficiency minus the incremental price paid for the efficiency gain. To determine the incremental price paid by consumers, we first have to estimate what the price would have been in the absence of the efficiency improvement (counterfactual price). Examples in Japan and Korea discussed above and examples in several other countries for other appliances and equipment indicate that efficiency policies and efficiency improvements do not increase inflation-adjusted prices over time and may in fact reduce prices compared to the counterfactual prices (Taylor, Spurlock, & Yang, 2015; Van Buskirk, Kantner, Gerke, & Chu, 2014). However, at any given point in time, prices of efficient ACs appear to be higher than prices for conventional ACs, and engineering estimates also indicate that at any given point in time, it costs more to produce efficient ACs. This creates the possibility that AC prices could increase with efficiency in the absence of technological change, economies of scale, or supply-side responses. To represent both of these possibilities, we consider two scenarios:

(i) In the first scenario, we assume that accelerating efficiency improvements will have no impact on prices, which is in line with historical experience.

(ii) The second scenario is a highly conservative consumer-benefit scenario, in which we assume that the prices will increase as a result of efficiency improvements. We estimate the incremental prices based on engineering estimates of efficiency improvement and corresponding cost data provided by Indian manufacturers (see (Shah et al., 2016) and the Appendix for details). This approach is used in the US and EU regulatory process to set the minimum energy performance standards. Studies have shown that, this approach will likely underestimate consumer benefits. This is because ex-post empirical assessments show that prices continue to decline at the historical rates even after the policy intervention and increase in efficiency (Van Buskirk et al., 2014).[12] Also, prices have systematically been below those projected by MEPS program analyses historically (Spurlock, 2014).

We find that even in the conservative benefits case accelerated efficiency improvement of room ACs is cost-effective from the consumer perspective; i.e., the electricity bill savings are much higher than the incremental price of the efficient AC. Figure 11 shows an example of estimating the net consumer benefit for an individual consumer in 2018. In the BAU trajectory, the one-star level in 2018 is expected to be ISEER 3.1 (specified by BEE); the market average ISEER is expected to be about 3.5. In the accelerated efficiency-improvement scenario, the one-star level is assumed to be ratcheted up to ISEER 3.5 in 2018; the market average efficiency would be ISEER 3.9. Figure 11 shows the estimated retail prices of the AC with ISEER 3.9 and AC with ISEER 3.5 (BAU); it also shows the NPV of electricity bill over the life of the AC assuming a discount rate of 8%, AC life of seven years, electricity tariff of Rs 6/kilowatt hour (kWh) increasing at 6% per year, and AC usage of 1,200 hours per year.

[12] Note that the reduction in prices appears to result in part from reduction in manufacturer markups.

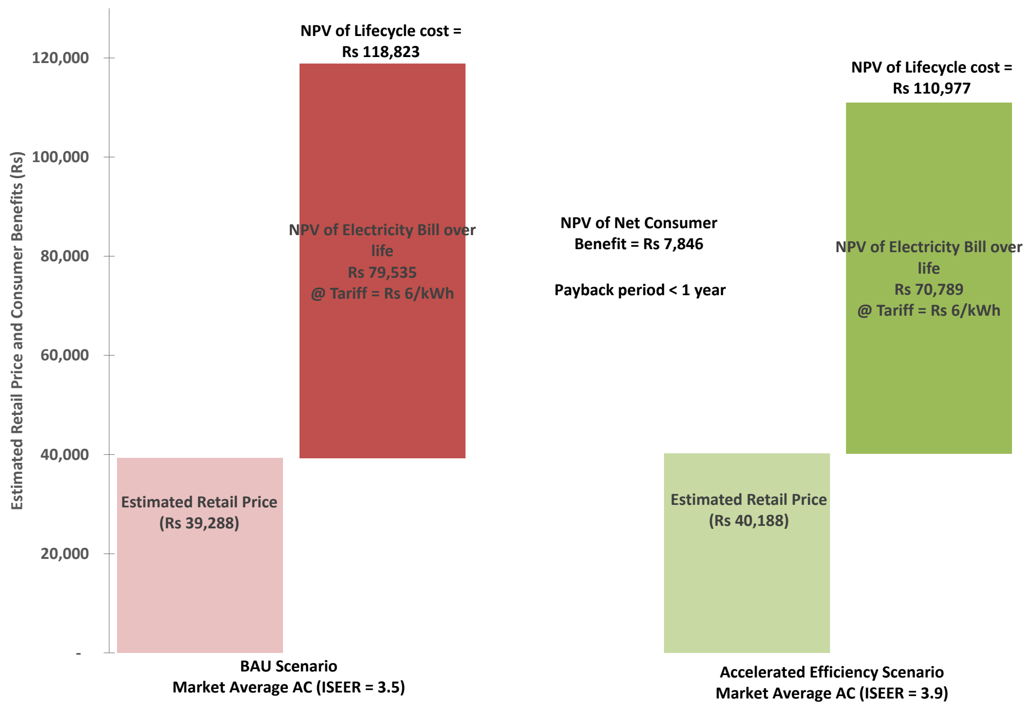


Figure 11: Estimating the net consumer benefit for an individual consumer in 2018

We find that consumers benefit from accelerated AC efficiency even with aggressive ratcheting of MEPS in 2018 and under the most conservative assumptions about price changes. The incremental price of an efficient AC (ISEER 3.9) is estimated at Rs 900 (maximum value) over the conventional AC (ISEER 3.5), and the electricity bill savings would be about Rs 1,400 per year; in other words, consumers can recover the incremental price in less than one year. NPV of the consumer benefit is in the range of Rs 4,000-6,000 per consumer. Note that this consumer benefit estimation is extremely conservative and should be considered a minimum bound. This is because: (a) the estimated electricity bill savings are based on conservative assumptions about AC usage hours and electricity prices, and (b) we have estimated the incremental retail price of the efficient AC based on the current technology costs, assuming no subsequent technology innovation, economies of scale, or supply-side response.

The net consumer benefit estimate is sensitive to the electricity tariff assumption. If the marginal electricity tariffs are Rs 8/kWh (increasing at 6%), the net consumer benefits would increase; in the case presented in Figure 11, the NPV of net consumer benefit would increase to Rs 10,761, and the payback period would shorten even more.

Figure 12 shows the NPV of the net consumer benefit in the accelerated efficiency-improvement scenario when the benefits are added over all consumers and discounted up to 2030.

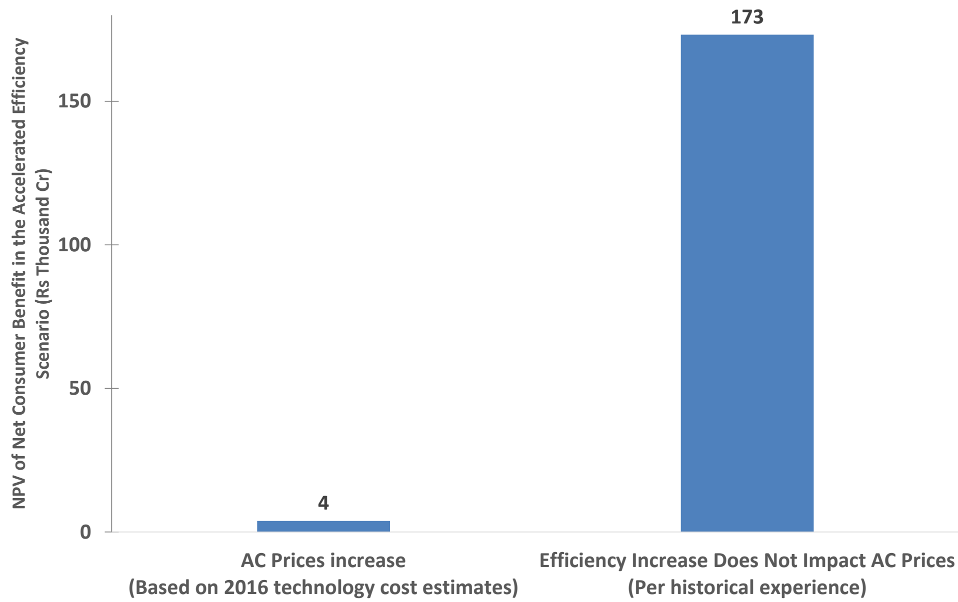


Figure 12: NPV of net consumer benefit from accelerated efficiency improvement

Key Assumptions: Hours of room AC use: 1,200 hours/yr; Electricity price: Rs 6/kWh in 2016 increasing at 6% per year; Discount rate: 8% for estimating NPV; life of AC: 7 years. Note that the net benefits estimates are merely indicative because the electricity prices and hours of use may change in the future.

The NPV of the net consumer benefit between 2018 (the first year of the proposed aggressive ratcheting of efficiency levels) and 2030 would range between Rs 4,000 crore (Cr) or US$ 600 million at the minimum (if AC prices increase with efficiency) to Rs 173,000 Cr or US$ 25 billion in a more realistic case (if efficiency increase does not impact AC prices, per historical experience). In addition, AC efficiency improvement will have a significant peak-load-reduction benefits for the utility. Please refer to (Abhyankar et al., 2013; Newsham, Birt, & Rowlands, 2011) for additional information on the peak-load benefits.

Manufacturers incur costs to produce and sell efficient ACs. We have attempted to capture most of these costs in the incremental manufacturing cost and retail price assessments (please see Appendix for more details). However, certain long-term and indirect costs (such as changes in the supply chain, transaction costs, and financing costs) cannot be captured in standard manufacturing cost assessments. Moreover, accelerated efficiency improvement may improve manufacturers' overall global competitiveness, potentially leading to increasing shares of the global market. A more comprehensive assessment could estimate the full impact on manufacturers, which is outside the scope of our study. However, we believe that the results of that estimate would be unlikely to change the key findings in this report.

4.3 Rebound Effect

One of the common concerns when assessing the validity of cost-benefit estimates from any appliance efficiency improvement is the rebound effect. The direct rebound effect (increase in energy use as a result of effective increase in consumers' disposable income because of increased energy efficiency) is found to be 8-12% for most appliance efficiency improvements in developed countries in the short and medium term (Borenstein, 2013; Gillingham, Rapson, & Wagner, 2016). In emerging economies, greater direct rebound effects on electricity consumption are observed than in developed countries; these effects tend to vary over a wide range between 12 and 46% (Gillingham et al., 2016). However, the consumption patterns in emerging economics change rapidly; therefore, estimating short-term demand elasticities and accurately estimating the rebound effect are very hard. Also, the rebound effect implies an increase in the consumption of cooling services and thus an overall increase in consumer welfare. The indirect rebound effect (increase in the consumption of other commodities resulting from the reduction in energy expenditures) is hard to predict and typically small (Borenstein, 2013; Gillingham et al., 2016). The rebound effect will likely have no impact on peak-load savings because even if room ACs are used for more hours, their peak coincidence will likely remain unchanged.

In Figure 13, we show the impact on the net consumer financial benefits from a range of direct rebound effect values for the developing countries mentioned earlier (10% to 50%). The benefits are shown for the two scenarios of future room AC prices.

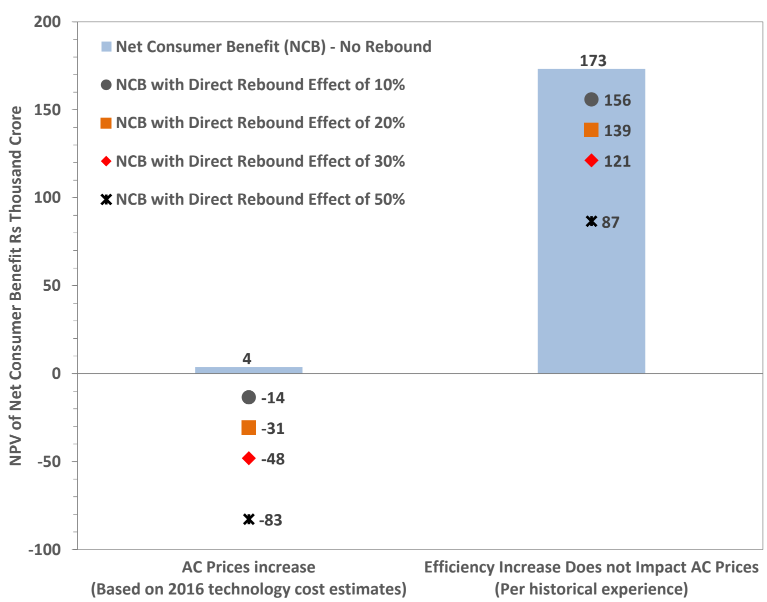


Figure 13: Impact of rebound effect on net consumer benefit

With the rebound effect, room AC operating hours might increase, reducing total electricity bill saving and significantly reducing the net consumer financial benefits. If room AC prices increase (based on the 2014 engineering cost estimates), the net consumer benefit might, in fact, be negative for higher rebound effect values. If room AC efficiency improvement does not impact AC prices, net consumer benefit would be as high as Rs 87,000 Cr even with a high direct rebound of 50%.

If the net consumer benefit is very high (especially if the efficiency improvement does not affect AC prices), AC penetration might increase; i.e., consumers who would not have purchased an AC in the BAU scenario might now purchase one. This would reduce the overall energy and peak-load savings. However, it would also substantially increase consumer welfare because of increased cooling service. For more information on the welfare benefits of cooling and improved indoor environments, please refer to (Fisk, 2000a, 2000b).

4.4 Sensitivity Analysis

The total energy savings, peak-load reduction, and net consumer benefit estimates are based on a number of assumptions about room AC sales growth, hours of use, and peak coincidence factor. To test the sensitivity of our results to these parameters, we re-estimate the benefits in a range of +/- 25% of the original values of these factors. Table 3 summarizes the results.

Table 3: Sensitivity on key parameters of energy savings, peak-load reduction, and net consumer benefit in the accelerated AC efficiency-improvement scenario

	Base Case	Sensitivity to Peak Coincidence Factor		Sensitivity to Hours of Use		Sensitivity to AC Sales Growth	
Room AC sales growth % per year	12.5%	12.5%		12.5%		**9.4%**	**15.6%**
Hours of use/year	1,200	1,200		**900**	**1,500**	1,200	
Peak coincidence factor	0.7	**0.525**	**0.875**	0.7		0.7	
Total energy saving at bus-bar in 2030 (TWh/yr)	64	64	64	48	80	48	80
Total peak-load reduction at bus-bar in 2030 (GW)	39	29	49	39	39	29	49
NPV of net consumer benefit (if AC prices increase) – Rs thousand Cr	4	4	4	-39	47	3	5
NPV of net consumer benefit (if efficiency improvement has no impact on AC prices) Rs thousand Cr	173	173	173	130	217	130	217

A low peak coincidence factor would imply that fewer ACs are used coincidentally, but it would not change the energy consumption. Conversely, if the hours of use per year are greater than 1,200, this might not affect the overall peak load attributable to ACs. However, it would increase the total electricity bill savings for consumer, so the net consumer benefit would increase substantially. If the AC sales growth is less than 12.5% per year, the energy savings, peak-load reduction, and net consumer benefit numbers would all decrease (in the same proportion) because the total number of ACs (stock) would be smaller.

5 Discussion and Conclusion: Policies and Programs to Accelerate Room AC Efficiency Improvement

In this report, we assess the technical feasibility, costs-benefits to consumers, and required policy enhancements for accelerating room AC efficiency improvement in India. The efficiency of room ACs in India increased by about 35% between 2006 and 2016 (3% per year) as a results of S&L even as inflation-adjusted room AC prices continued to decline. Room AC penetration is expected to grow rapidly in India so that, by 2030, room ACs would likely contribute nearly 140 GW (about 30%) to total peak load, assuming that efficiency continues to improve at 3% per year. Examples from Japan and Korea show that energy-efficiency policies play a significant role in accelerating AC efficiency with no apparent long-term impact on prices. These examples also show that efficiency can be improved at a rate that is significantly greater than has been achieved historically in India. In India, the most efficient room AC is almost twice as efficient as the average AC sold on the market, so there are no technology constraints that would prevent India from accelerating AC efficiency improvements at a rate comparable to that achieved in Japan and Korea. Further, our analysis shows that accelerated AC efficiency improvement will have enormous benefits for India. For example, if the market average efficiency is improved at 6% per year instead of the historical rate of 3% per year, by 2030, 30-50 additional GW of peak load (equivalent to 60-100 power plants of 500 MW each) could be avoided, and more than 64 TWh/yr in electricity use (equivalent to the current electricity consumption of the entire state of Gujarat) could be saved. The net consumer savings will range from Rs 4,000 Cr ($600 million) to Rs 173,000 Cr ($25 billion). In addition, accelerated efficiency improvement will likely strengthen the capacity of Indian manufacturers to compete in the global market. In the subsections below, we discuss key policy and program options for accelerating the room AC efficiency improvement in India.

5.1 Accelerated Ratcheting Up of Bureau of Energy Efficiency Star Rating Levels

Experience in India and several other countries has shown that efficiency is strongly driven by MEPS (e.g., the one-star rating level) and related energy-efficiency labeling levels. For example, in India, two- and three-star-labeled ACs dominate the market; the weighted average market efficiency approximately equals the two or three-star level even with increasing stringency of the star labels. Hence, accelerating the ratcheting up of star levels is one strategy to accelerate efficiency. Note that this does not mean that the revisions would need to be made more frequently but only that the stringency of the star-labels would be increased compared to the historical trajectory.

5.2 Providing Policy Direction with Medium- and Long-Term Targets for Star Levels

Similar to Japan's Top Runner program, a long-term target can provide a broad policy direction that informs the setting and revision of interim targets; i.e., today's best available technology in India can be the target for the market average efficiency level (two- to three-star level) by 2022. Given the historical relationship between market average and MEPS levels, this can be achieved by setting today's five-star level (4.5 ISEER) as the MEPS (one-star level) in 2022. Note that several brands (Bluestar, Godrej, Hitachi, Voltas) already sell models with efficiency of ISEER 4.5 and higher. A two-star level of ISEER 5 in 2022 will achieve an efficiency improvement at the rate that Japan and Korea achieved historically. An additional long-term target could be to make today's globally available best commercial technology the market average by 2030; i.e., the market average could be ISEER 7.9[13] and MEPS (one-star level) would be ISEER 7.1 by 2030. Once such long-term targets are specified, BEE can ratchet up MEPS in the interim years. The standard practice so far has been that efficiency for all star levels increases by one star equivalent every two years; this has resulted in an efficiency improvement of ~3% per year. One of the options for an accelerated ratcheting up is widening the spread of the star labels, which incentivizes more efficient products to be sold on the market; then, the star levels could be ratcheted up every two years by two stars instead of one.[14] For example, within three revisions (up to 2022), the current five-star label could become the MEPS (one-star label).

Figure 14 shows a potential schedule of ratchets to achieve the accelerated efficiency-improvement trajectory with two long-term goals in mind: (a) today's five-star level becomes the one-star label in 2022 (ISEER 4.5), and (b) today's globally available best commercial technology becomes the market average in 2030 (market average of ISEER 7.9 and one-star label of ISEER 7.1).

[13] This is equivalent to the globally best available technology of Korean CSPF 9.4, converted to the ISEER metric.
[14] With product unification from 2018 onward, widening the spread of the star labels has already started, e.g. one-star label of ISEER 3.1 and five-star label of ISEER 4.5.

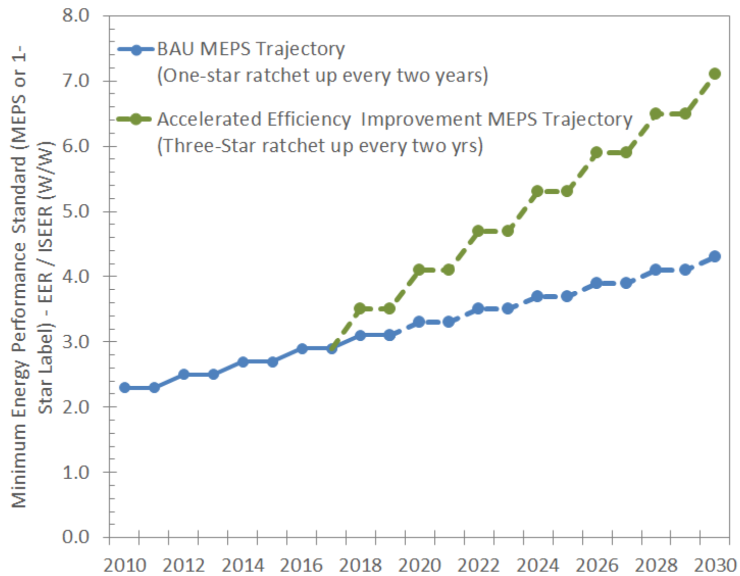


Figure 14: Potential schedule of ratcheted-up levels for alternative trajectories for room AC minimum standard (one-star level) improvement

Note that Figure 14 shows one possible pathway for ratcheting up of star levels. The most appropriate pathway should be identified based on inputs from several stakeholders.

5.3 Bulk Procurement and Incentives to Support Accelerated Ratcheting Up of Standards and Labeling Levels

Building on the historical success of the BEE star-labeling program, the Indian government recently announced its intent to accelerate the sale of efficient air conditioners using a program similar to the successful UJALA LED program (MoneyControl, 2016). Bulk procurement can reduce the cost of efficient air conditioners, and incentives can address the first-cost barrier, resulting in an increase in their uptake. Such programs will be crucial for supporting the accelerated ratcheting up of star levels. For example, increasing the market share of today's five-star ACs will allow an easier transition to the same efficiency level being characterized as a two- or three-star level a few years down the line because such programs will help efficient products to be sold as the norm. Incentive and bulk procurement programs can be used to bring products that are more efficient than today's five-star level to the market. However, design of such programs is crucial to ensuring that overall benefits are maximized because of the “free-rider” effect (i.e., consumers taking advantage of an incentive when they would have purchased the appliance without the incentive or would have done so with a smaller incentive). See for example Boomhower & Davis (2014), which gives examples from Mexico's residential refrigerator replacement program of 2009 and argues that most households would have participated even for much lower subsidy amounts.

5.4 Star Rating for Other Types of Space-Cooling Equipment

A similar accelerated trajectory based on the most efficient commercially available models can be followed for other types of space-cooling equipment including chillers, variable- refrigerant-flow multi-split ACs, ducted split ACs, and rooftop ACs as their penetration also increases in the Indian market. Note that development of star ratings for different equipment types will require a number of related interventions such as development of test procedures, capacity building of test labs, development of appropriate efficiency metrics, and integration with building codes and standards.

6 Appendix: Assumptions Regarding Air-Conditioner Efficiency Improvement, Prices, Sales, Energy and Peak Projections, and Consumer Costs-Benefits

6.1 Air-Conditioner Efficiency Trajectory

We have created two scenarios for how the AC MEPS (one-star level) would be revised in the future: BAU and accelerated efficiency improvement. In the BAU case, we take the BEE specified levels up to 2019 and assume that the MEPS are ratcheted up at the historical rate of 3.0% per annum; by 2030, the room AC MEPS reaches an ISEER of 4.2. The accelerated efficiency improvement scenario can be viewed as a target to be achieved by enhanced policy interventions. We assume that the room AC MEPS is revised to 3.5 in 2018 (compared to 3.1 specified by BEE) and is ratcheted up thereafter at 6% per year, which is double the historical rate. Over the next 10 years, i.e. by 2026, the room AC MEPS would nearly double the current level (from ISEER 2.9 to 5.7), and by 2030 the room AC MEPS would reach an ISEER of 7.1. Table A1 shows the room AC MEPS (one-star levels) up to 2030 for the two scenarios: BAU and accelerated efficiency improvement.

Table A1: BAU and Accelerated Efficiency Improvement One-Star MEPS Levels

	2010	*2015*	*2018*	*2020*	*2022*	*2025*	*2030*
BAU	2.3	2.7	3.1	3.2	3.4	3.7	4.2
Accelerated efficiency improvement	#N/A		3.5	3.9	4.4	5.3	7.1

6.2 AC Prices

To know the incremental price paid by the consumers, we first have to estimate what the price would have been in the absence of efficiency improvement (counterfactual price). We base it on the engineering estimates of the incremental manufacturing costs of efficiency improvement from Shah et al (2016). On top of these manufacturing costs, we add 140% markup for wholesale and retail costs and profits; this markup is also taken from (Shah et al., 2016). We then use the same methodology to estimate the retail AC prices in case of the accelerated efficiency improvement scenario. Note that (Shah et al., 2016) show the efficiency improvement only up to ISEER 6.0. For estimating AC prices beyond ISEER 6.0, we use linear extrapolation with the ratio of estimated prices and ISEER up to ISEER 6.0. Table A2 shows the estimated retail AC prices for a range of ISEER levels.

Table A2: Estimated AC Prices for a Range of ISEER Levels

Market Average ISEER (Wh/Wh)	Equivalent Market Average EER (W/W)*	Estimated Retail Price in Rs (based on 2016 technology cost assessments)
3.7	3.5	39,588
3.9	3.7	40,188
4.1	3.8	44,436
4.4	4.0	48,300
4.6	4.2	48,828
4.9	4.4	53,076
5.2	4.6	55,404
5.5	4.8	64,212
5.8	4.9	65,940
6.1	5.1	72,608
6.5	5.3	77,370
6.9	5.4	82,131
7.3	5.6	86,892

*Note: A particular value of ISEER could be achieved by multiple combinations of efficient components such as efficient compressors, better heat transfer coefficient and higher area (i.e. higher U.A value) of heat exchangers, variable-speed drives, etc. Our engineering economic model chooses the efficient components to minimize the total manufacturing cost for reaching an ISEER level. Therefore, depending on the components chosen, the same ISEER level may have multiple EERs or vice versa.

6.3 Net Consumer Benefit

Net consumer benefit for a given level of cooling service is the NPV of the electricity bill savings resulting from efficiency minus the incremental price paid for the efficiency gain. The electricity bill savings are estimated by multiplying the energy savings from efficient ACs by the electricity price for each year in the life of the AC. The net consumer benefits of all ACs added up to 2030 are then discounted to 2016 to estimate the NPV of the net consumer benefit.

Table A3 shows our assumptions.

Table A3: Assumptions for Calculating Net Consumer Benefit

Parameter	Assumption
AC size	1.5 tons (5.25 kW)
Hours of use	1,200 hours/yr
AC annual energy consumption	(AC size / ISEER value) * Hours of use
Electricity price	6 Rs/kWh in 2016 increasing at 6% per annum
Discount rate	8%
AC life	7 years

6.4 Air-Conditioner Sales, Stock, Total Energy Consumption, and Peak Load

Room AC sales have been growing at a CAGR of more than 10 over the last 10-15 years. In the future, rising incomes, urbanization, and falling appliance prices are expected to support continuation of the same trend. We assume that between 2016 and 2030, room AC sales grow at a CAGR of 10% per year. Conservatively assuming an average life of about seven years, we then estimate the total stock of room ACs in India. For estimating the total energy consumption at the bus-bar, we assume the transmission and distribution loss would be 15%. Because ISEER is a seasonal energy-efficiency metric, it cannot be directly used for estimating the kW rating of an AC or the AC's peak load contribution. Based on the temperature distribution and seasonal test conditions in India and the engineering options available for efficiency improvement, we estimate the equivalent EER level (Shah et al 2016). This EER value (W/W) is then used to estimate the kW input rating of the AC. Based on (Phadke et al., 2013), we use a peak coincidence factor of 0.7 and transmission and distribution loss of 15% to assess the concurrent AC peak load at bus-bar. Tables A4 andA5 summarize the key assumptions and results.

Table A4: Assumptions for Calculating Peak Load

Parameter	**Assumption**
AC sales growth CAGR	12.5% per year
AC life	7 years
Transmission and Distribution loss	15%
Peak coincidence factor	0.7
AC input rating (kW)	AC Size (in kWR) / EER Value
AC peak load (bus-bar)	(AC input rating * peak coincidence factor) / (1 – transmission and distribution loss)

Table A5: Summary of Sales, Stock, Energy, and Peak-Load Projections

	2015	**2020**	**2025**	**2030**
Room AC sales (millions/yr)	4*	8	14	24
Room AC live stock (millions)	24	38	69	124
Total room AC consumption at bus-bar (BAU scenario), TWh/yr	60	81	126	197
Total room AC peak load at bus-bar (BAU scenario), GW	35	48	78	134

* Source: (Shah et al., 2016)

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